NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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TESTS IN THE VARIABLE-DENSITY TUNNEL OF SEVEN TAPERED WINGS HAVING N.A.C.A. 230 MEAN LINES

By Raymond F. Anderson
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INTRODUCTION

At the request of the Matériel Division of the Army Air Corps, seven tapered wings having sections based on the N.A.C.A. 230 mean line were tested in the variable-density wind tunnel. The characteristics of the wings were as follows:

Wing	Plan form	Aspect ratio	Taper ratio	Root section	Tip section
N.A.C.A.				N.A.C.A.	N.A.C.A.
23015-09	Standard Army	6	2-1	23015	23009
23018-09	Standard Army	6	2-1	23018	23009
3-10-18	Straight taper, rounded tips	10	3-1	23018	23009
5-10-16	Straight taper, rounded tips	10	5-1	23016	23009
5-10-18	Straight taper, rounded tips	10	5-1	23018	23009
5-12-16	Straight taper, rounded tips	12	5-1	23016	23009
5-12-20	Straight taper, rounded tips	12	5-1	23020	23009

The standard Army plan form is the plan form given in the "Handbook of Instructions for Airplane Designers," vol. I, p. 76 f. The two wings having this plan form were

designated in the manner previously used for wings of standard plan form tested in the variable-density tunnel. The five remaining wings differed only in taper ratio, aspect ratio, and root thickness, therefore numbers giving these three quantities were used to identify these wings. The ordinates of the wings are given in the attached table and details of shape are given in the accompanying drawings. Each model had an area of 150 square inches and was constructed of duralumin.

TESTS AND RESULTS

The lift, drag, and pitching moment of the wings were measured in the variable-density tunnel at a pressure of 20 atmospheres. In addition, the maximum lift was measured at one-fifth the standard dynamic pressure to indicate scale effect. The results are presented in the form of the usual dimensionless coefficients (corrected for tunnel-wall effect) on the accompanying plots. To find the Reynolds Number of the tests, a length defined by area/span was used. The maximum lift coefficients apply in flight at an effective Reynolds Number which is equal to a turbulence factor 2.64 multiplied by the test Reynolds Number. The coefficient C_{D_e} has been corrected to effective Reynolds Number by allowing for the reduction in skin friction drag due to the change from the test to the effective Reynolds Number. For a test Reynolds Number of 3,000,000 the reduction amounts to $\Delta c_d = 0.0011$. In computing the correction, the variation of Reynolds Number along the span of the wings was taken into account.

The effective profile drag coefficient C_{D_e} is obtained by subtracting the induced drag coefficient of an elliptical wing:

$$C_{D_e} = C_D - \frac{C_L^2}{\pi A}$$

where A is the aspect ratio. It should be noted that C_{D_e} is not a profile drag coefficient but applies only to the particular wing tested. C_{D_e} is useful for comparing the drag of tapered wings, as it includes the true profile drag and any additional induced drag caused by departure from the ideal elliptical lift distribution.

The pitching-moment coefficients $C_{m_{ac}}$ are given about an axis through the aerodynamic center of the wings in order to obtain a practically constant value of moment coefficient. The location of the aerodynamic center is given on the plots by coordinates which are expressed as fractions of S/b (area/span).

It will be noted that the wings of high aspect ratio and taper ratio have considerably reduced maximum lift coefficients as compared to the wings of aspect ratio 6 and 2 to 1 taper. The low maximum lift coefficients are undoubtedly due to a premature stalling of the tip sections owing to the high taper ratios, the low Reynolds Number for the tip sections and the thin sections employed near the tips.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 19, 1936.

TABLE I

N. A. C. A. 23015-09 Tapered Airfoil

Stations in percent of chord	Ordinates in percent of chord									
	Root section		Construction tip section		Section I		Section II		Section III	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	-	0	-	0	-	0	-	0	-	0
1.25	3.34	-1.54	2.04	-.91	2.34	-1.08	2.24	-1.03	2.12	-.95
2.5	4.44	-2.25	2.83	-1.19	3.22	-1.46	3.10	-1.37	2.94	-1.29
5	5.89	-3.04	3.93	-1.44	4.44	-1.86	4.26	-1.72	4.07	-1.55
7.5	6.91	-3.61	4.70	-1.63	5.26	-2.13	5.06	-1.95	4.86	-1.76
10	7.64	-4.09	5.26	-1.79	5.84	-2.37	5.64	-2.18	5.41	-1.94
15	8.52	-4.84	5.85	-2.17	6.52	-2.84	6.29	-2.61	6.04	-2.36
20	8.92	-5.41	6.06	-2.55	6.78	-3.27	6.54	-3.02	6.26	-2.75
25	9.08	-5.78	6.11	-2.80	6.86	-3.55	6.60	-3.30	6.32	-3.02
30	9.05	-5.96	6.05	-2.96	6.80	-3.71	6.54	-3.45	6.26	-3.16
40	8.59	-5.92	5.69	-3.03	6.41	-3.75	6.16	-3.50	5.89	-3.23
50	7.74	-5.50	5.09	-2.86	5.75	-3.53	5.53	-3.30	5.26	-3.04
60	6.61	-4.81	4.32	-2.53	4.89	-3.10	4.69	-2.91	4.47	-2.69
70	5.25	-3.91	3.42	-2.08	3.88	-2.54	3.73	-2.38	3.54	-2.20
80	3.73	-2.83	2.41	-1.51	2.74	-1.85	2.63	-1.74	2.51	-1.62
90	2.04	-1.59	1.31	-.86	1.49	-1.05	1.43	-.98	1.36	-.92
95	1.12	-.90	.72	-.50	.82	-.60	.78	-.56	.74	-.52
100	.16	-.16	.10	-.10	.11	-.11	.10	-.10	.10	-.10
L.E. radius	2.48		0.89		1.21		1.10		0.98	
Slope of radius through end of chord	0.305									

N. A. C. A. 23018-09 Tapered Airfoil

Stations in percent of chord	Ordinates in percent of chord									
	Root section		Construction tip section		Section I		Section II		Section III	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	-	0	-	0	-	0	-	0	-	0
1.25	4.09	-1.83	2.04	-.91	2.51	-1.17	2.34	-1.09	2.17	-.99
2.5	5.29	-2.71	2.83	-1.19	3.42	-1.59	3.23	-1.45	2.99	-1.29
5	6.92	-3.80	3.93	-1.44	4.68	-2.07	4.44	-1.84	4.15	-1.62
7.5	8.01	-4.60	4.70	-1.63	5.53	-2.38	5.26	-2.12	4.94	-1.82
10	8.83	-5.22	5.26	-1.79	6.14	-2.66	5.83	-2.36	5.49	-2.03
15	9.86	-6.18	5.85	-2.17	6.86	-3.18	6.51	-2.83	6.13	-2.45
20	10.36	-6.86	6.06	-2.55	7.15	-3.63	6.78	-3.26	6.36	-2.84
25	10.56	-7.27	6.11	-2.80	7.23	-3.93	6.85	-3.54	6.43	-3.11
30	10.55	-7.47	6.05	-2.96	7.18	-4.08	6.79	-3.70	6.36	-3.27
40	10.04	-7.37	5.69	-3.03	6.78	-4.12	6.40	-3.74	5.99	-3.33
50	9.05	-6.81	5.09	-2.86	6.08	-3.85	5.74	-3.52	5.36	-3.13
60	7.75	-5.94	4.32	-2.53	5.18	-3.39	4.88	-3.10	4.56	-2.77
70	6.18	-4.82	3.42	-2.08	4.11	-2.76	3.87	-2.52	3.61	-2.27
80	4.40	-3.48	2.41	-1.51	2.91	-2.01	2.74	-1.84	2.55	-1.66
90	2.39	-1.94	1.31	-.86	1.58	-1.13	1.50	-1.04	1.38	-.94
95	1.32	-1.09	.72	-.50	.87	-.65	.82	-.59	.76	-.54
100	.19	-.19	.10	-.10	.12	-.12	.11	-.11	.10	-.10
L.E. radius	3.56		0.89		1.39		1.21		1.02	
Slope of radius through end of chord	0.305									

TABLE I (Continued)

N. A. C. A. 3-10-18 Tapered Airfoil

Stations in percent of chord	Ordinates in percent of chord							
	Root section		Construction tip section		Section I		Section II	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	-	0	-	0	-	0	-	0
1.25	4.09	-1.83	2.04	-.91	2.24	-1.03	2.12	-.95
2.5	5.89	-2.71	2.83	-1.19	3.10	-1.37	2.94	-1.29
5	8.32	-3.80	3.93	-1.44	4.26	-1.72	4.07	-1.55
7.5	8.01	-4.60	4.70	-1.63	5.06	-1.95	4.86	-1.76
10	8.83	-5.22	5.26	-1.79	5.64	-2.18	5.41	-1.94
15	9.86	-6.18	5.85	-2.17	6.29	-2.61	6.04	-2.36
20	10.36	-6.86	6.06	-2.55	6.54	-3.02	6.26	-2.75
25	10.56	-7.27	6.11	-2.80	6.60	-3.30	6.32	-3.02
30	10.55	-7.47	6.05	-2.96	6.54	-3.45	6.26	-3.16
40	10.04	-7.37	5.69	-3.03	6.16	-3.50	5.89	-3.23
50	9.05	-6.81	5.09	-2.86	5.53	-3.30	5.26	-3.04
60	7.75	-5.94	4.32	-2.53	4.69	-2.91	4.47	-2.69
70	6.18	-4.82	3.42	-2.08	3.73	-2.38	3.54	-2.20
80	4.40	-3.48	2.41	-1.51	2.63	-1.74	2.51	-1.62
90	2.39	-1.94	1.31	-.86	1.43	-.98	1.36	-.92
95	1.32	-1.09	.72	-.50	.78	-.56	.74	-.52
100	.19	-.19	.10	-.10	.10	-.10	.10	-.10
L. E. radius	3.56		0.89		1.10		0.98	
Slope of radius through end of chord					0.305			

N. A. C. A. 5-10-16 Tapered Airfoil

Stations in percent of chord	Ordinates in percent of chord							
	Root section		Construction tip section		Section I		Section II	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	-	0	-	0	-	0	-	0
1.25	3.59	-1.64	2.04	-.91	2.24	-1.03	2.12	-.95
2.5	4.71	-2.39	2.83	-1.19	3.10	-1.37	2.94	-1.29
5	6.22	-3.51	3.93	-1.44	4.26	-1.72	4.07	-1.55
7.5	7.28	-3.94	4.70	-1.63	5.06	-1.95	4.86	-1.76
10	8.03	-4.47	5.26	-1.79	5.64	-2.18	5.41	-1.94
15	8.97	-5.29	5.85	-2.17	6.29	-2.61	6.04	-2.36
20	9.40	-5.90	6.06	-2.55	6.54	-3.02	6.26	-2.75
25	9.57	-6.27	6.11	-2.80	6.60	-3.30	6.32	-3.02
30	9.55	-6.46	6.05	-2.96	6.54	-3.45	6.26	-3.16
40	9.07	-6.40	5.69	-3.03	6.16	-3.50	5.89	-3.23
50	8.18	-5.94	5.09	-2.86	5.53	-3.30	5.28	-3.04
60	6.99	-5.18	4.32	-2.53	4.69	-2.91	4.47	-2.69
70	5.57	-4.21	3.42	-2.08	3.73	-2.38	3.54	-2.20
80	3.96	-3.04	2.41	-1.51	2.63	-1.74	2.51	-1.62
90	2.15	-1.70	1.31	-.86	1.43	-.98	1.36	-.92
95	1.19	-.97	.72	-.50	.78	-.56	.74	-.52
100	.17	-.17	.10	-.10	.10	-.10	.10	-.10
L.E. radius	2.82		0.89		1.10		0.98	
Slope of radius through end of chord					0.305			

TABLE I (Continued)

N. A. C. A. 5-10-18 Tapered Airfoil

Stations in percent of chord	Ordinates in percent of chord							
	Root section		Construction tip section		Section I		Section II	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	-	0	-	0	-	0	-	0
1.25	4.09	-1.83	2.04	-.91	2.24	-1.03	2.12	-.95
2.5	5.29	-2.71	2.83	-1.19	3.10	-1.37	2.94	-1.29
5	6.92	-3.80	3.93	-1.44	4.26	-1.72	4.07	-1.55
7.5	8.01	-4.60	4.70	-1.63	5.06	-1.95	4.86	-1.76
10	8.83	-5.22	5.26	-1.79	5.64	-2.18	5.41	-1.94
15	9.86	-6.18	5.85	-2.17	6.29	-2.61	6.04	-2.36
20	10.36	-6.86	6.06	-2.55	6.54	-3.02	6.26	-2.75
25	10.56	-7.27	6.11	-2.80	6.60	-3.30	6.32	-3.02
30	10.55	-7.47	6.05	-2.96	6.54	-3.45	6.26	-3.16
40	10.04	-7.37	5.69	-3.03	6.16	-3.50	5.89	-3.23
50	9.05	-6.81	5.09	-2.86	5.53	-3.30	5.26	-3.04
60	7.75	-5.94	4.32	-2.53	4.69	-2.91	4.47	-2.69
70	6.18	-4.82	3.42	-2.08	3.73	-2.38	3.54	-2.20
80	4.40	-3.48	2.41	-1.51	2.63	-1.74	2.51	-1.62
90	2.39	-1.94	1.31	-.86	1.43	-.98	1.36	-.92
95	1.32	-1.09	.72	-.50	.78	-.56	.74	-.52
100	.19	-.19	.10	-.10	.10	-.10	.10	-.10
L.E. radius	3.56		0.89		1.10		0.98	
Slope of radius through end of chord					0.305			

N. A. C. A. 5-12-16 Tapered Airfoil

Stations in percent of chord	Ordinates in percent of chord							
	Root section		Construction tip section		Section I		Section II	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	-	0	-	0	-	0	-	0
1.25	3.59	-1.64	2.04	-.91	2.20	-1.00	2.12	-.95
2.5	4.71	-2.39	2.83	-1.19	3.05	-1.34	2.94	-1.29
5	6.22	-3.31	3.93	-1.44	4.23	-1.67	4.07	-1.55
7.5	7.28	-3.94	4.70	-1.63	5.01	-1.89	4.86	-1.76
10	8.03	-4.47	5.26	-1.79	5.59	-2.11	5.41	-1.94
15	8.97	-5.29	5.85	-2.17	6.21	-2.53	6.04	-2.36
20	9.40	-5.90	6.06	-2.55	6.45	-2.94	6.26	-2.75
25	9.57	-6.27	6.11	-2.80	6.52	-3.21	6.32	-3.02
30	9.55	-6.46	6.05	-2.96	6.46	-3.36	6.26	-3.16
40	9.07	-6.40	5.69	-3.03	6.08	-3.42	5.89	-3.23
50	8.18	-5.94	5.09	-2.86	5.45	-3.22	5.26	-3.04
60	6.99	-5.18	4.32	-2.53	4.63	-2.84	4.47	-2.69
70	5.57	-4.21	3.42	-2.08	3.67	-2.33	3.54	-2.20
80	3.96	-3.04	2.41	-1.51	2.60	-1.70	2.51	-1.62
90	2.15	-1.70	1.31	-.86	1.41	-.96	1.36	-.92
95	1.19	-.97	.72	-.50	.77	-.55	.74	-.52
100	.17	-.17	.10	-.10	.10	-.10	.10	-.10
L.E. radius	2.82		0.89		1.06		0.98	
Slope of radius through end of chord					0.305			

TABLE I (Continued)

N. A. C. A. 5-12-20 Tapered Airfoil

Stations in percent of chord	Ordinates in percent of chord							
	Root section		Construction tip section		Section I		Section II	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	-	0	-	0	-	0	-	0
1.25	4.60	-2.00	2.04	-.91	2.24	-1.03	2.12	-.95
2.5	5.84	-3.00	2.83	-1.19	3.10	-1.37	2.94	-1.29
5	7.58	-4.30	3.93	-1.44	4.26	-1.72	4.07	-1.55
7.5	8.76	-5.22	4.70	-1.63	5.06	-1.95	4.86	-1.76
10	9.64	-5.97	5.26	-1.79	5.64	-2.18	5.41	-1.94
15	10.75	-7.07	5.85	-2.17	6.29	-2.61	6.04	-2.36
20	11.30	-7.81	6.06	-2.55	6.54	-3.02	6.26	-2.75
25	11.56	-8.25	6.11	-2.80	6.60	-3.30	6.32	-3.02
30	11.55	-8.46	6.05	-2.96	6.54	-3.45	6.26	-3.16
40	11.00	-8.33	5.69	-3.03	6.16	-3.50	5.89	-3.23
50	9.96	-7.71	5.09	-2.86	5.53	-3.30	5.26	-3.04
60	8.51	-6.71	4.32	-2.53	4.69	-2.91	4.47	-2.69
70	6.79	-5.42	3.42	-2.08	3.73	-2.38	3.54	-2.20
80	4.83	-3.92	2.41	-1.51	2.63	-1.74	2.51	-1.62
90	2.64	-2.18	1.31	-.86	1.43	-.98	1.36	-.92
95	1.45	-1.23	.72	-.50	.78	-.56	.74	-.52
100	.21	-.21	.10	-.10	.10	-.10	.10	-.10
L.E. radius	4.40		0.89		1.10		0.98	
Slope of radius through end of chord					0.305			

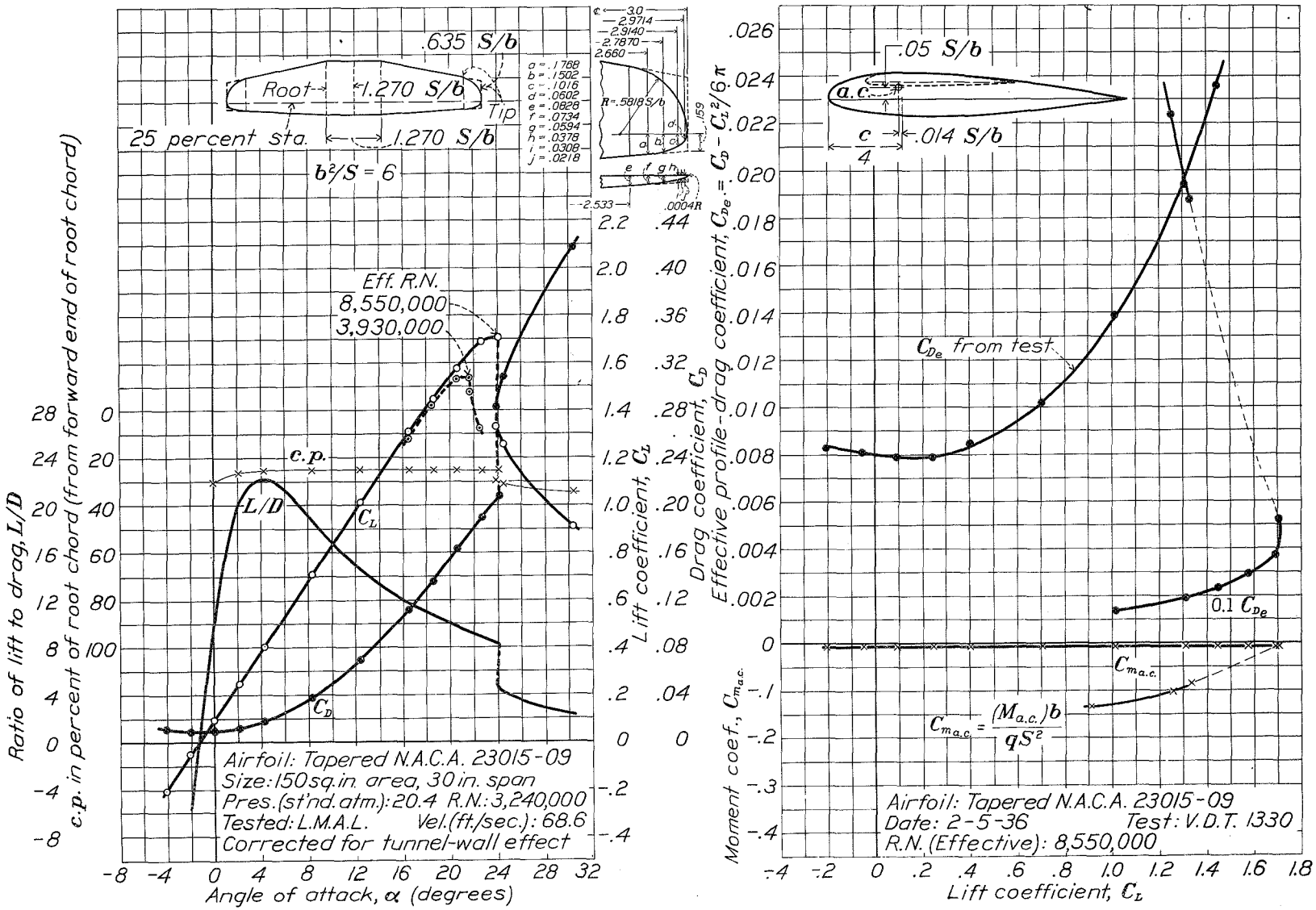

Figure 1.- Tapered N.A.C.A. 23015-09 airfoil.

N.A.C.A.

Fig. 1

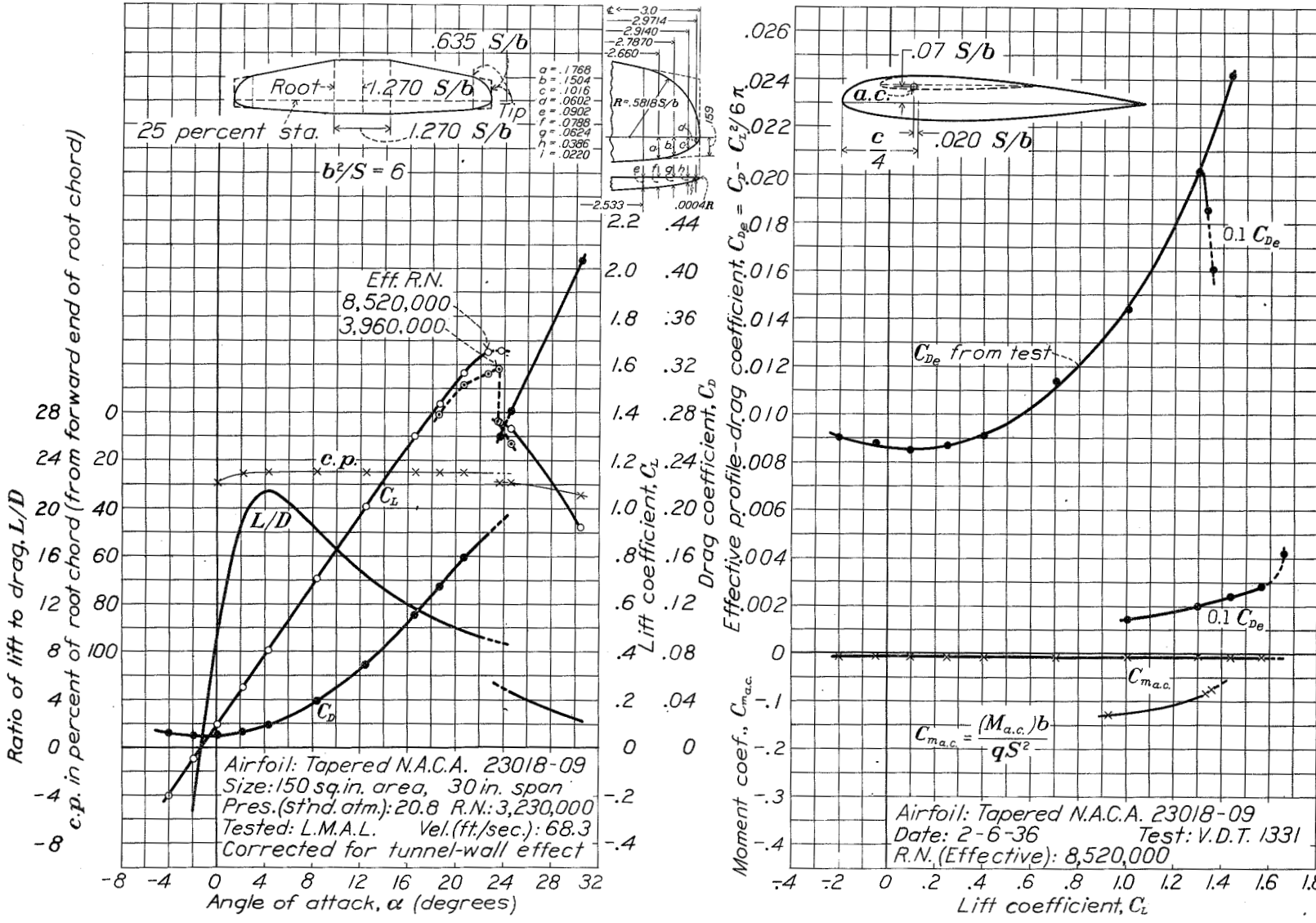

Figure 2.- Tapered N.A.C.A. 23018-09 airfoil.

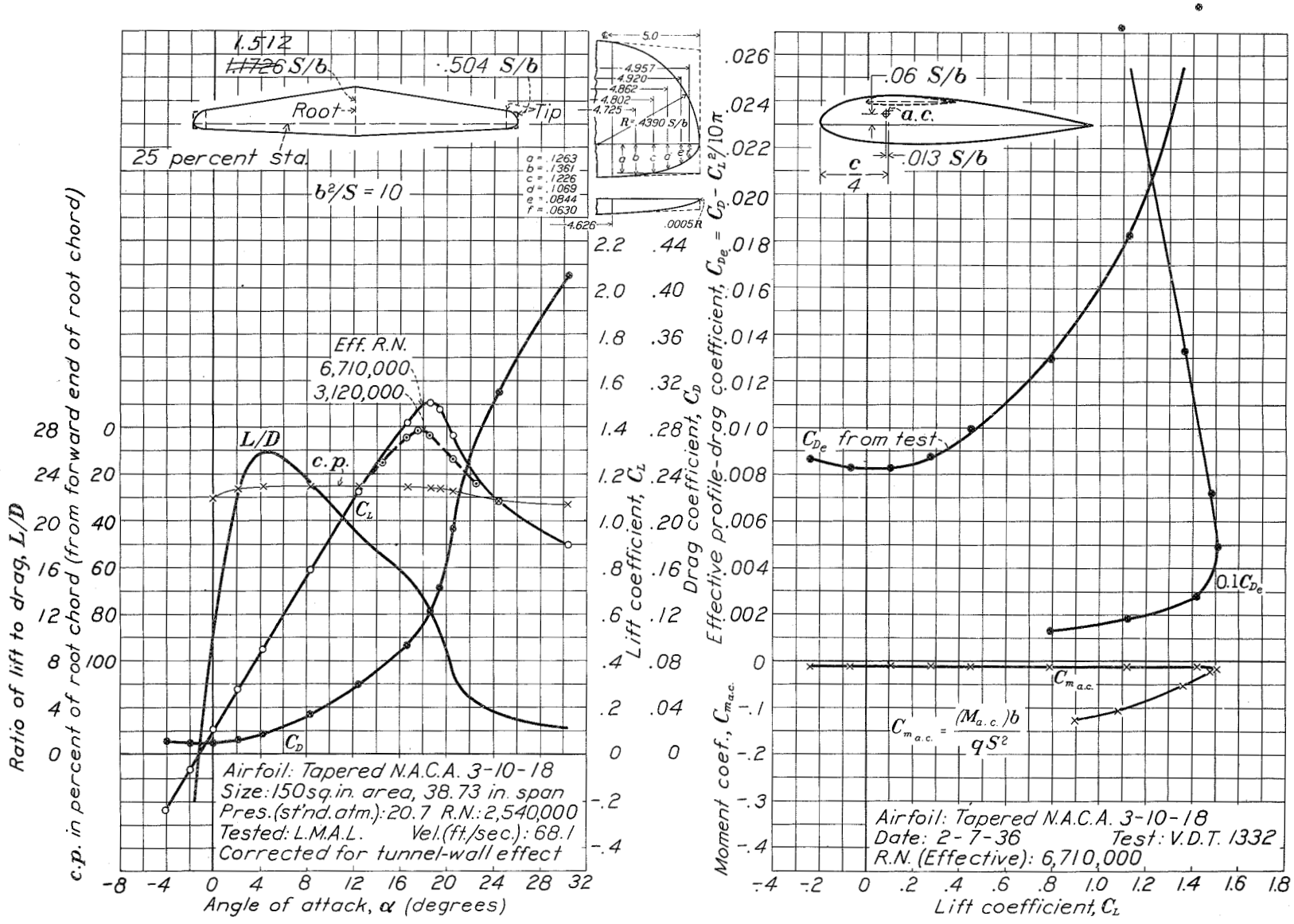

Figure 3.- Tapered N.A.C.A. 3-10-18 airfoil.

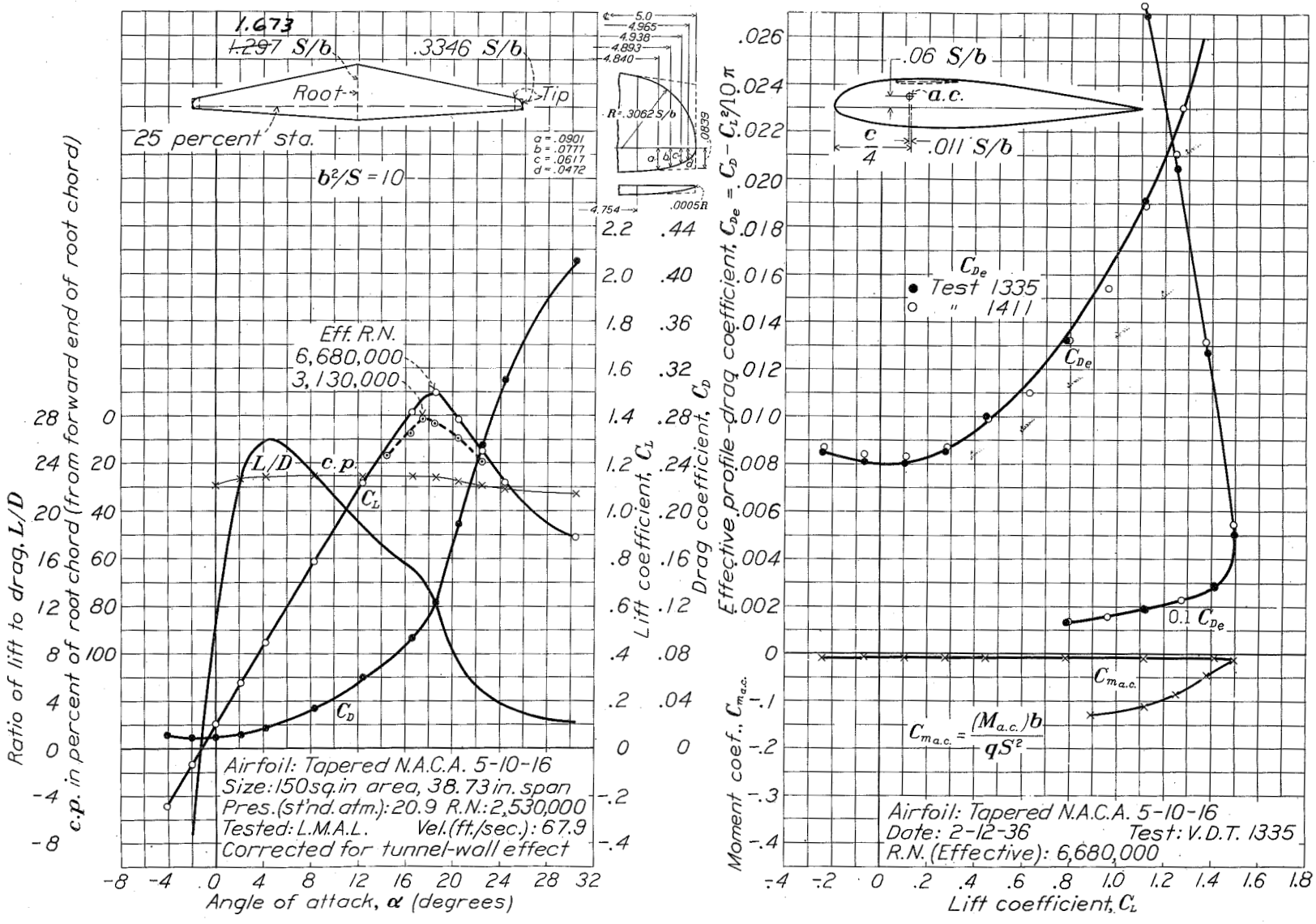

Figure 4.- Tapered N.A.C.A. 5-10-16 airfoil.

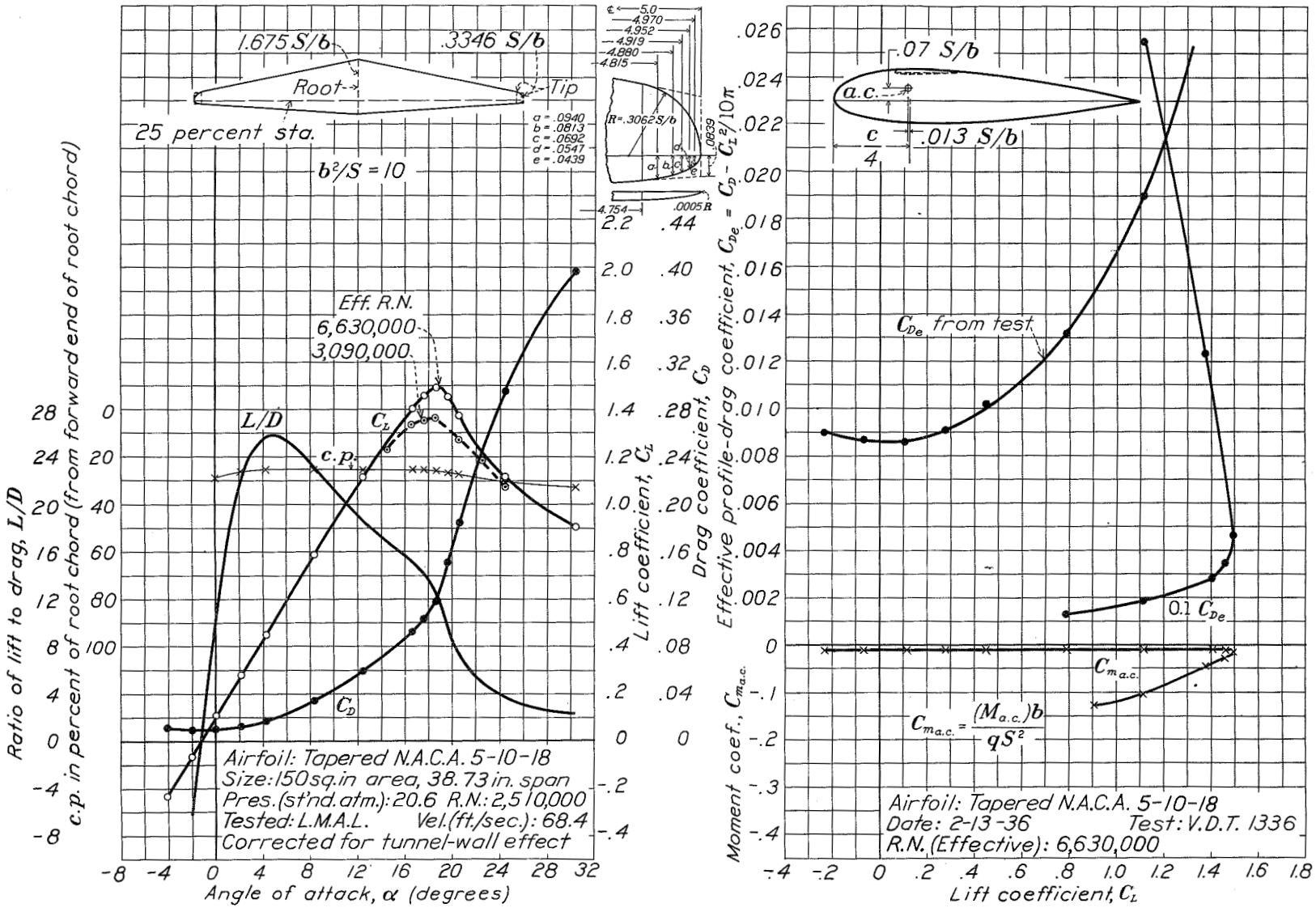

Figure 5.- Tapered N.A.C.A. 5-10-18 airfoil.

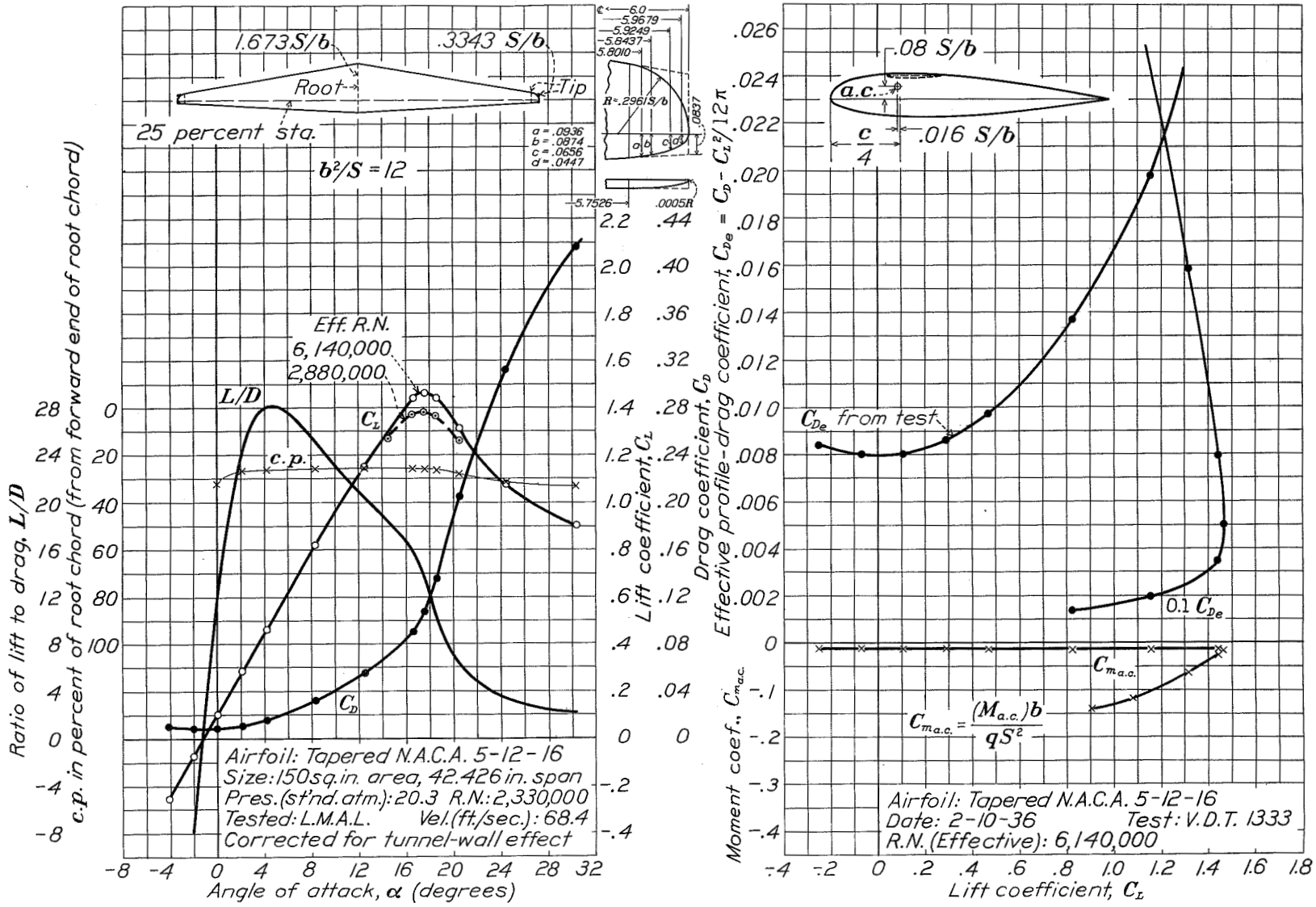

Figure 6.- Tapered N.A.C.A. 5-12-16 airfoil.

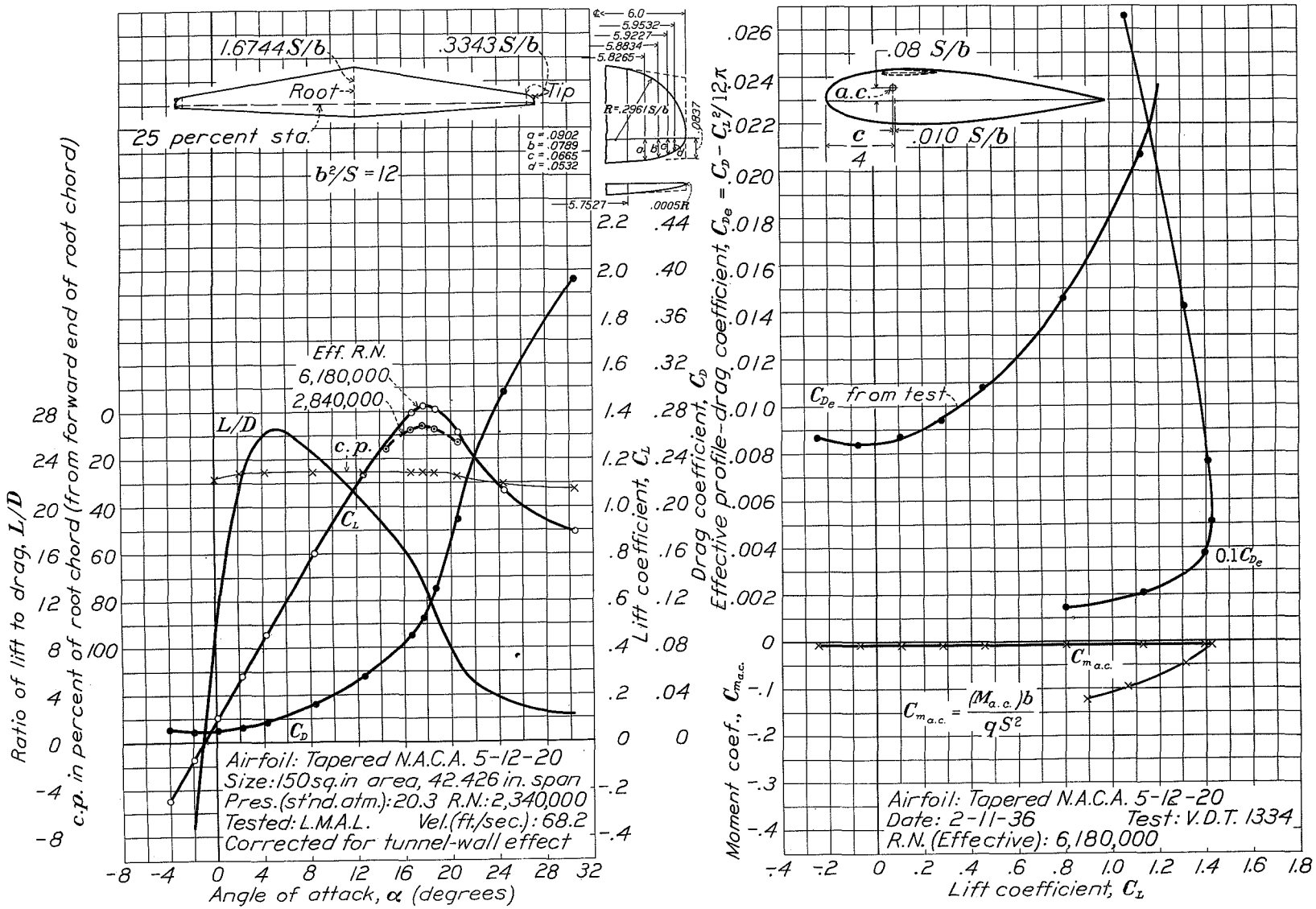

Figure 7.- Tapered N.A.C.A. 5-12-20 airfoil.